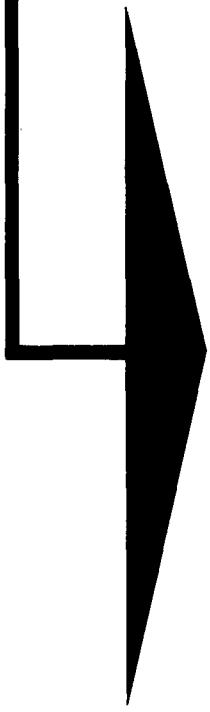
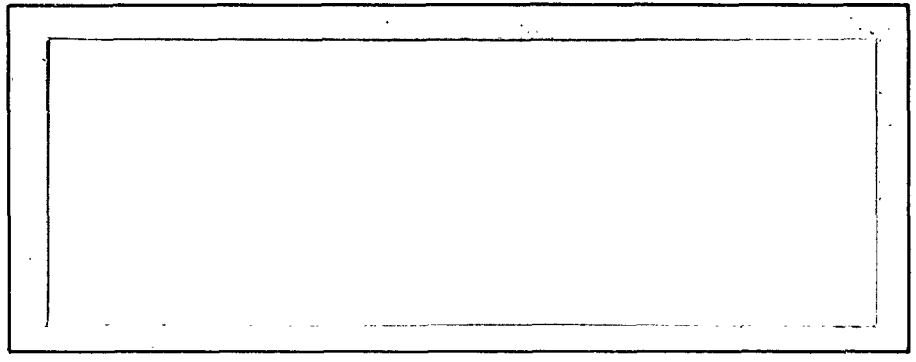


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**MELPAR**  **INC**

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3000 ARLINGTON BOULEVARD

FALLS CHURCH, VIRGINIA

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2000°F POWER WIRE  
FOR AEROSPACE  
ENVIRONMENT

First Quarterly Report

April 5, 1963 to July 5, 1963

Contract No. AF33(657)-11046  
Project No. 8128  
Task No. 812806

Prepared by

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Submitted to

Flight Accessories Laboratory  
Aeronautical Systems Division  
Air Force Systems Command  
United States Air Force  
Wright-Patterson AFB, Ohio

## FOREWORD

The work covered by this report was accomplished under Air Force Contract No. AF 33(657)-11046, but this report is being published and distributed prior to Air Force review. The publication of this report, therefore, does not constitute approval by the Air Force of the findings or conclusions contained herein. It is published for the exchange and stimulation of ideas.

## ABSTRACT

Resistivity and tensile properties as a function of temperature, to 2000°F, were measured for pure rhodium and platinum-coated molybdenum. Oxidation of these materials and their compatibility with various high-temperature insulators were also tested. The first attempt to produce power wire capable of functioning at 2000°F will consist of rhodium wire and MgO insulation enclosed in a platinum sheath.

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## I. INTRODUCTION

This report is for the first three-month period (April 5, 1963 to July 5, 1963) of work on Contract No. AF 33(657)-11046.

The objective of this contract is to develop electrical power wire capable of functioning at 2000°F under the following environmental conditions.

### Earth and Launch Environment

1. Humidity (0 - 100%)
2. Vibration (20 g - 80 to 2000 cps)
3. Shock (50 g)
4. Acceleration (10 g)

### Orbital Environment

1. Vacuum ( $10^{-9}$  torr)
2. Nuclear radiation (Neutrons  $> .5$  mev  $2 \times 10^{10}$  nv)  
(Gamma  $1.1 \times 10^8$  ergs/gm c-sec)

### Re-entry Environment

1. Temperature (2000°F)
2. Thermal shock (150°F/min)

While under these environmental conditions, the wire must be able to withstand 1200 volts to ground. The wire must be capable of being wound on a mandrel 25 times the wire diameter. Design objectives for the wire are a room-temperature resistivity of less than  $6 \times 10^{-6}$  ohm-cm and a tensile strength greater than 35,000 psi.

The objectives for the first phase of this project were to determine the properties of conductors and insulators as a function of temperature that could operate under the stated conditions.

The design of the completed wire system to be evaluated first will be as that shown in figure 31. This is similar to a design developed by Lewis Engineering,\* designated Lewis type III wire.

The conductor materials tested for the first part of the program were platinum-coated molybdenum and pure rhodium. The insulator material tested was magnesium oxide. Designs for terminals and end seals were also made.

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\*"High-Temperature Insulated Wire Development," AD 274906.

## II. TESTING AND DESIGN

### 1. Resistivity Measurements

The resistivity of the various conductors is measured using the standard four-terminal resistance method. This is shown schematically in figure 1. The four-terminal sample has its current leads in series with the current leads of a known four-terminal standard resistor. A constant, known current flows through both. The voltage across the standard and unknown resistances is measured by a potentiometer. The ratio of these voltages is the same as the ratio of the resistance. Thus, the resistance of the unknown sample is calculated using:

$$R_{\text{unknown}} = \frac{V_{\text{unknown}}}{V_{\text{standard}}} R_{\text{standard}}$$

Because the resistance of a uniform sample is given by:

$$R = \rho \frac{l}{A}$$

where  $R$  is the resistance of the unknown between the potential leads,  $l$  is the length between the potential leads, and  $A$  is the cross-sectional area,  $\rho_{\text{unknown}}$  is given by

$$\rho_{\text{unknown}} = \frac{RA}{l} = \frac{(R_{\text{standard}}) (V_{\text{unknown}})}{(V_{\text{standard}})} \frac{A}{l}$$

The sample used in preliminary tests of the system was a piece of platinum wire 0.0820 in diameter and 31 cm in length. The wire was laid out straight and two nicks were made 25 cm apart with a ground tool steel right-angle edge. The wire was then bent in a U shape so that the nicks were almost opposite each other. Two Inconel spring contacts with matching right-angle knife edges hold the sample to a lavite sample holder and form the potential leads. By using welded platinum leads to the Inconel contacts and having the potential leads close together, stray thermal emfs were made very small (less than 1 microvolt). Current contacts will be made by flame welding platinum leads to the ends of the sample. The voltages of the resistances are measured with a Leeds and Northrup K-3 potentiometer, as is the emf from the platinum-rhodium thermocouple in the furnace. The current

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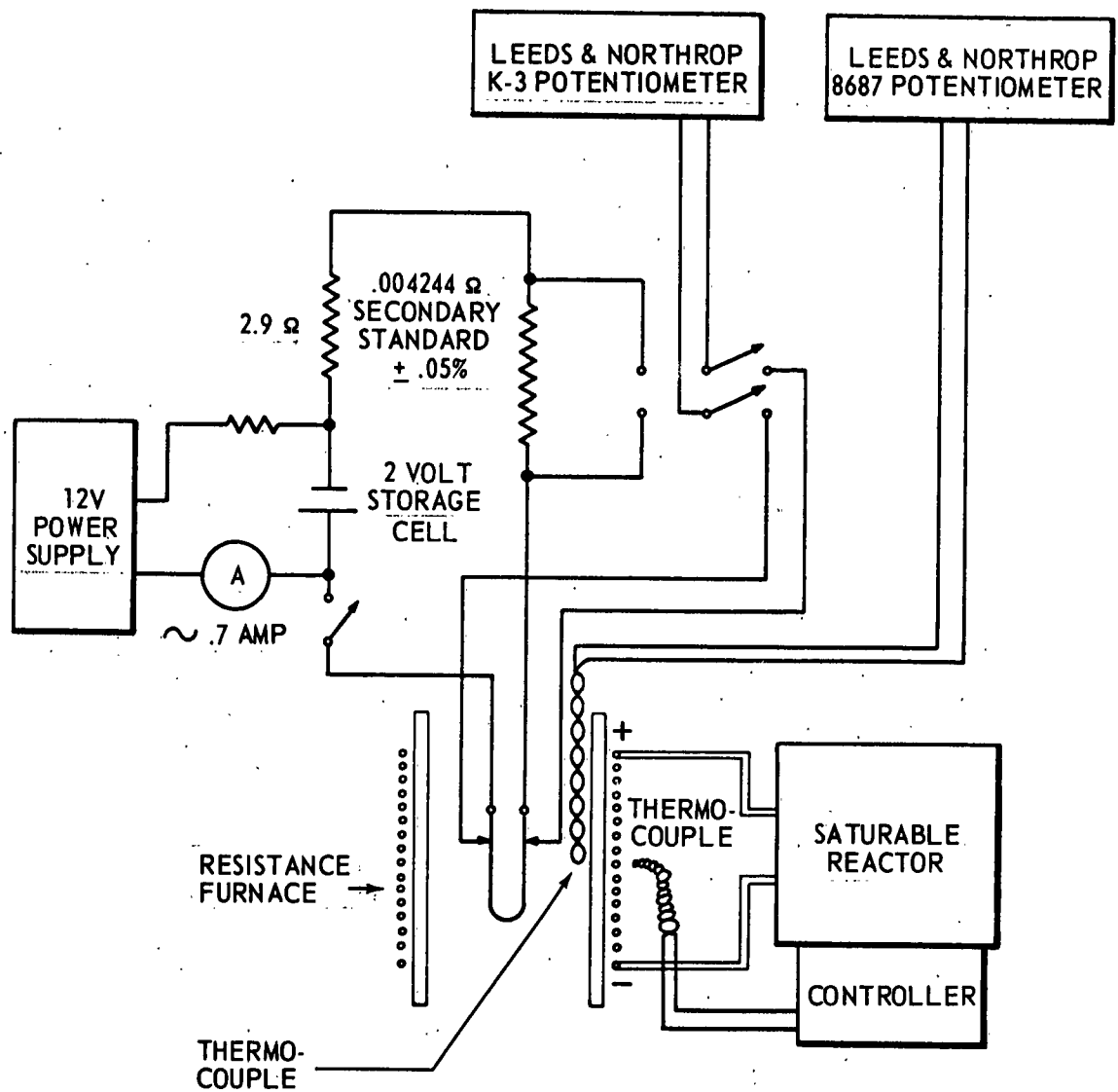


Figure 1. Schematic Drawing of Resistivity Measurement Equipment

for the series-connected standard resistance (.004244 ohm) and the unknown sample is obtained from a 2-volt storage cell in series with a 2.9-ohm resistor. The storage cell is charged from a constant current source at the same rate as the current through the sample to keep the current drift to a minimum.

It is possible that some of the materials to be used for conductors in this program may be subject to variation in resistance from one point to another along a given length of wire. To investigate this possibility, the room-temperature sample holder shown in figure 2 was designed. This holder will accommodate either 0.080- or 0.025-inch-diameter wire, and is provided with spring-loaded contact points located every two inches over a total span of 12 inches. By taking a series of readings along a length of wire and then moving the sample further and examining another length of wire, it is possible to investigate resistance variability without welding leads to the wire, or even cutting it.

To make elevated temperature measurements, the previously described lavite sample holder is placed inside the furnace and the resistivity measured as a function of temperature. The sample holder is mounted inside a large-mass nickel furnace liner to provide stability, and a hot zone with a gradient of  $+1^{\circ}\text{C}$  over the entire sample length. This equipment is shown in figure 3. In making the room-temperature resistance variability measurements, the same measuring equipment is used in conjunction with the room-temperature sample holder.

Table I gives the room-temperature resistivity results of all of the wires measured; uniformity in all instances was within 1% of the reported average values.

Figures 4 — 8 show the graphs of the resistivity of each of the conductor materials as a function of temperature. The bare molybdenum wire was measured in an atmosphere of argon; all other tests were run in air. Each graph has with it a table of actual resistivities measured at each test temperature, both during the heating cycle and the room-temperature values measured after cooling to ambient.

Comparing figures 5 and 6 and figures 7 and 8, it can be seen that rhodium has a lower resistivity than platinum-coated molybdenum at all of the temperatures investigated.

Annealing effects were noticed on the rhodium wire at temperatures above  $500^{\circ}\text{C}$ . The as-received, 22-gauge wire has a room-temperature ( $25^{\circ}\text{C}$ ) resistivity of  $5.19 \times 10^{-6}$  ohm-cm. After the wire was heated to  $1000^{\circ}\text{C}$  in the resistivity-measuring apparatus, the 22-gauge rhodium had a resistivity of  $5.09 \times 10^{-6}$  ohm-cm.

The rhodium tested was supplied by Engelhard Industries, Inc., and was stated to be 99.8% pure. Most of the impurities were platinum-group metals.

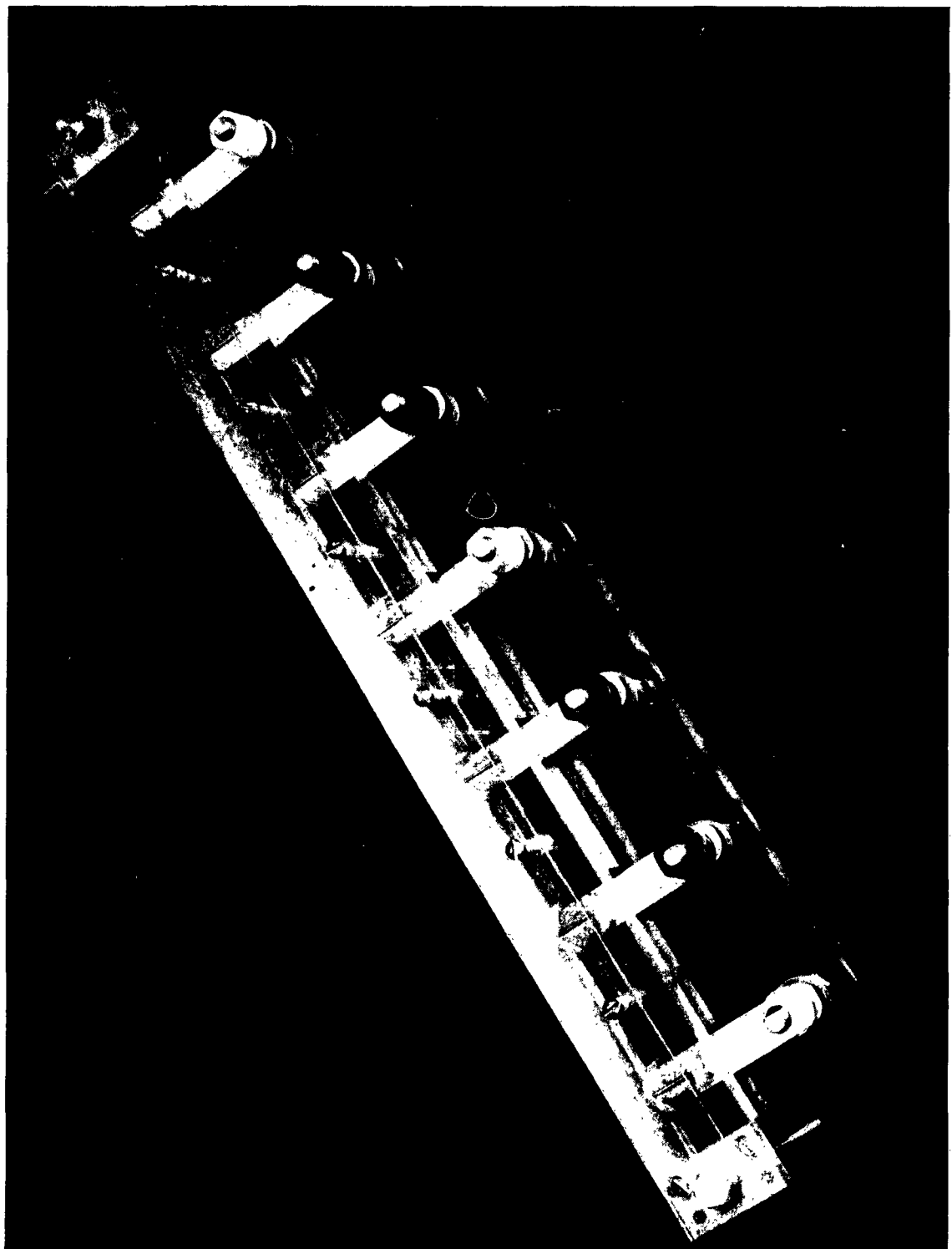


Figure 2. Room-Temperature Resistivity Sample Holder



Figure 3. Resistivity-Measuring Apparatus

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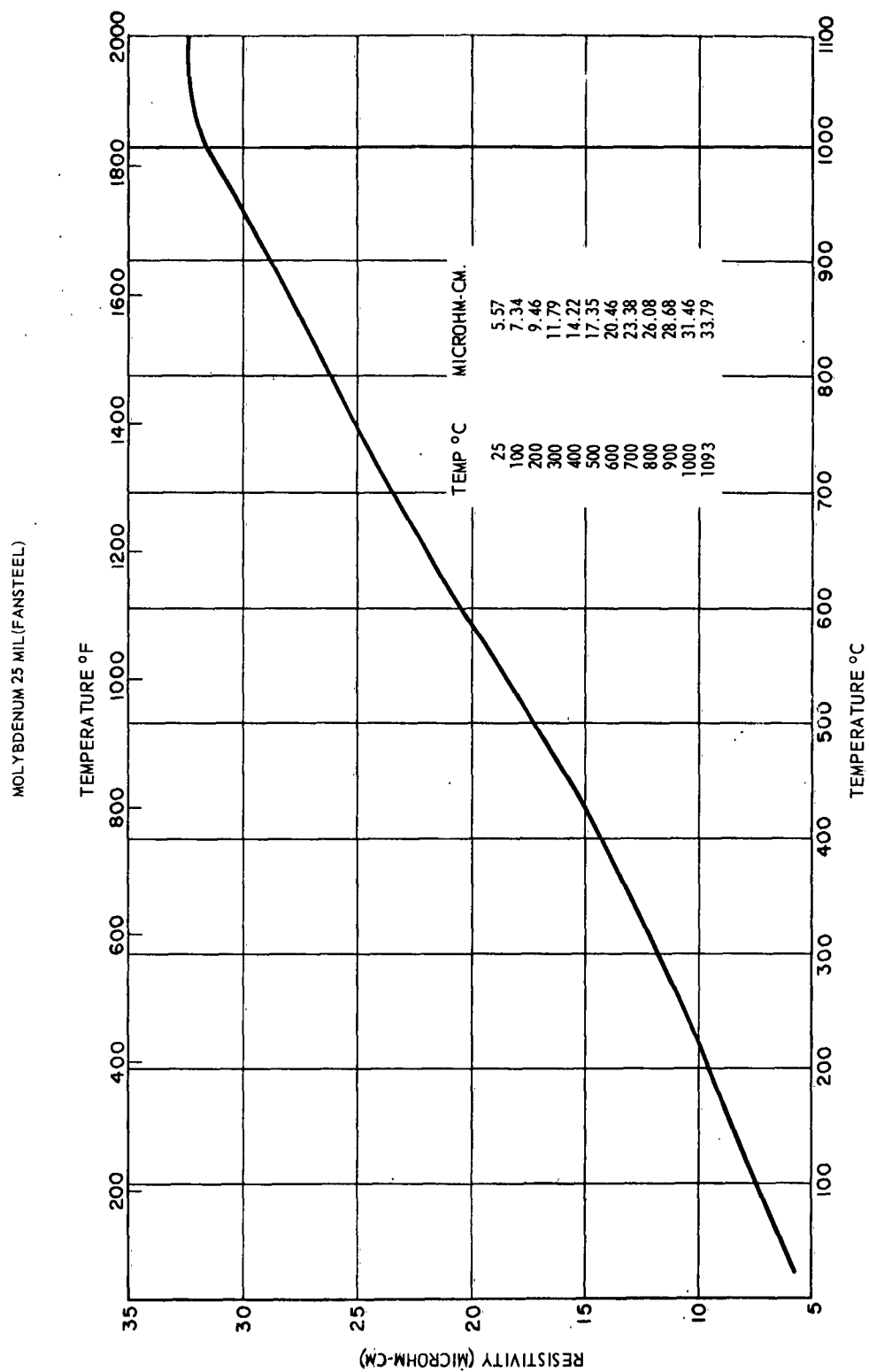


Figure 4. Resistivity vs. Temperature for 22-Gauge Molybdenum

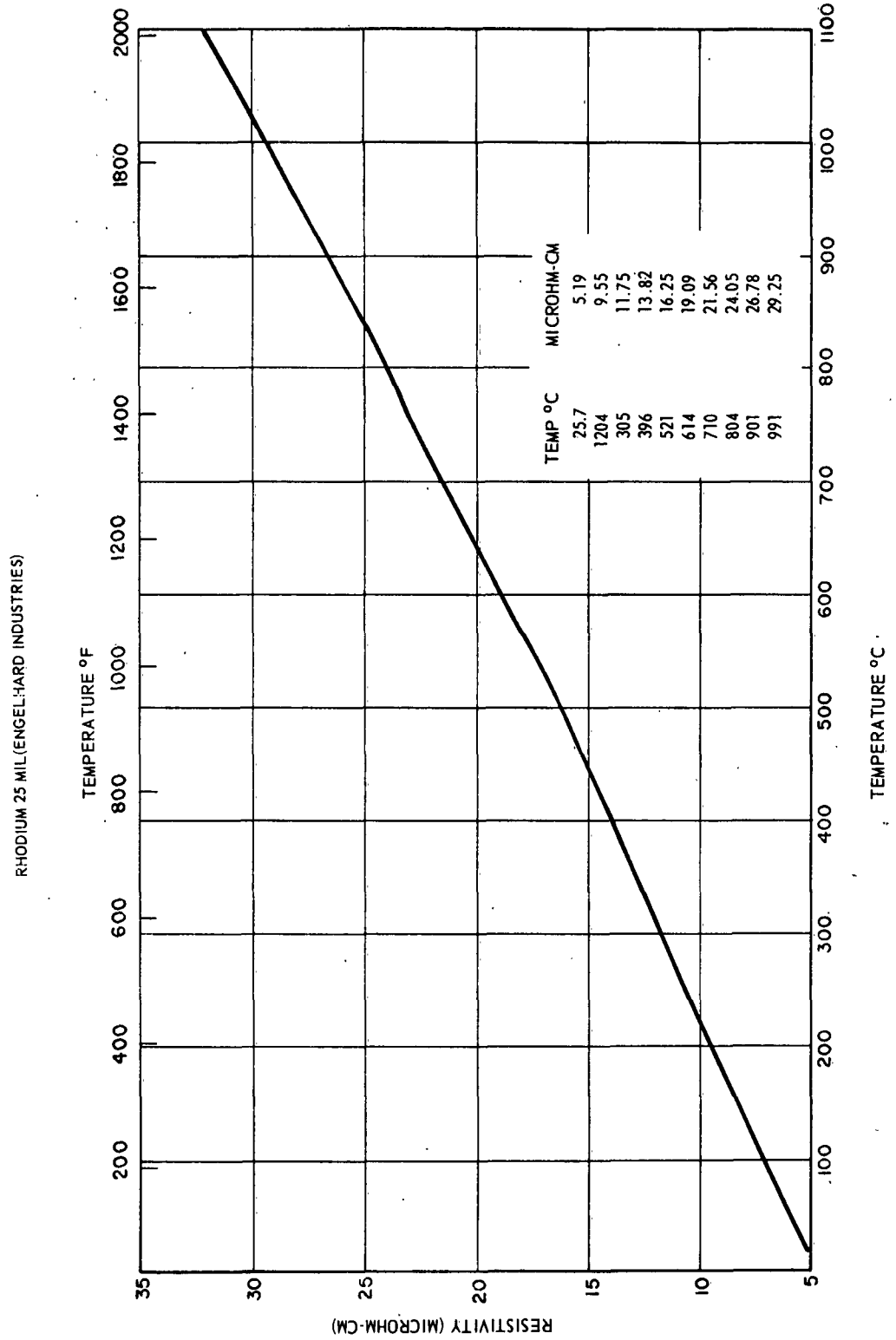


Figure 5. Resistivity vs. Temperature for 22-Gauge Rhodium



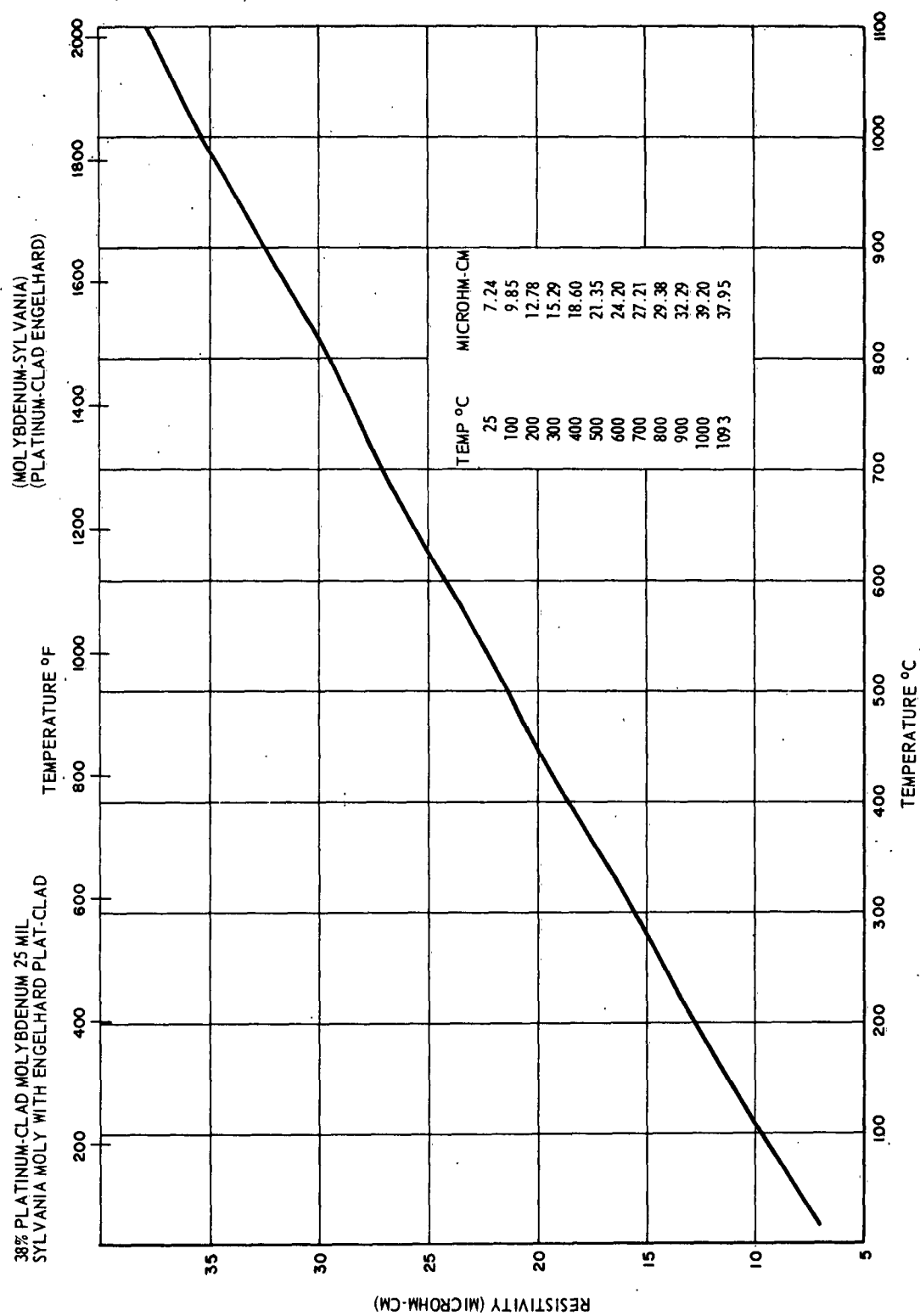


Figure 6. Resistivity vs. Temperature for 22-Gauge, Platinum (38%)-Clad Molybdenum

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(ENGELHARD INDUSTRIES)

RHODIUM 81 MIL.

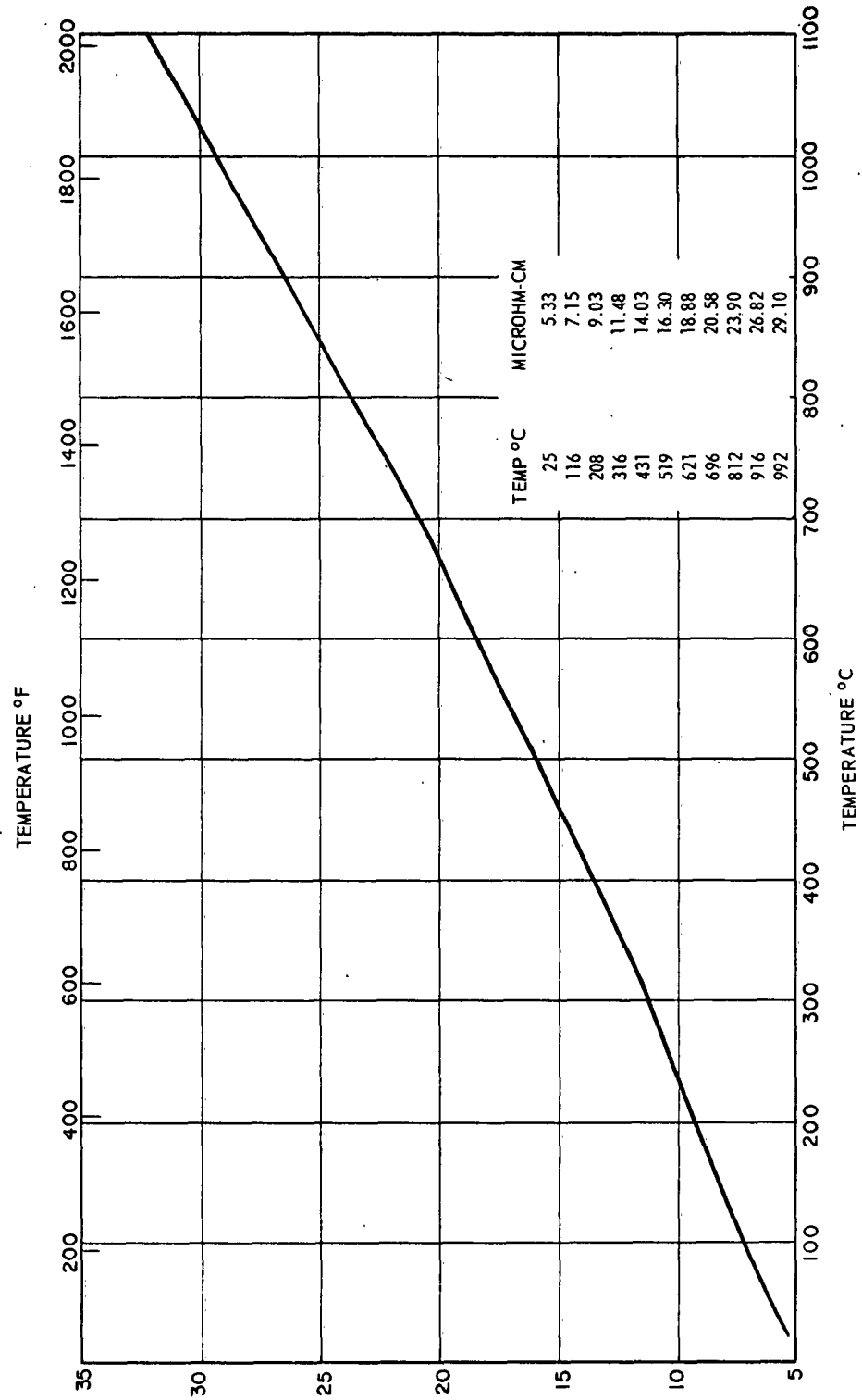


Figure 7. Resistivity vs. Temperature for 12-Gauge Rhodium

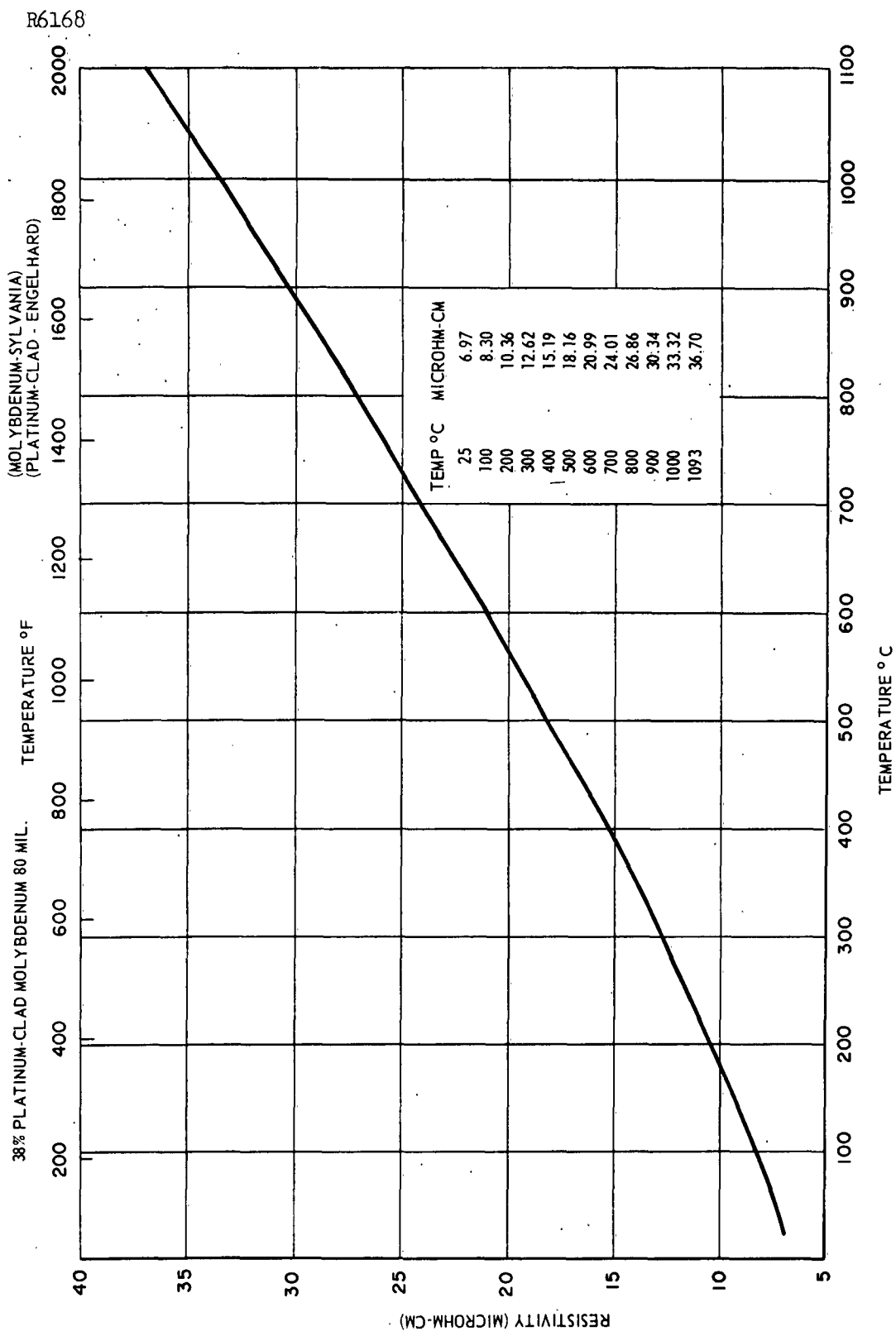


Figure 8. Resistivity vs. Temperature for 12-Gauge, Platinum (38%)-Coated Molybdenum

Table I

## ROOM-TEMPERATURE RESISTIVITIES, 25°C

## Molybdenum (Sylvania)

25 mil		80 mil	6.19 microhm-cm
632 circular mil	6.35 microhm-cm		
650 circular mil	6.45 microhm-cm		
652 circular mil	6.46 microhm-cm		

## Molybdenum (Fansteel)

25 mil	5.57 microhm
--------	--------------

## Platinum-clad molybdenum\*

25 mil		80 mil	
14%	6.49 microhm-cm	14%	6.68 microhm-cm
25%	6.80 microhm-cm	25%	6.82 microhm-cm
38%	7.26 microhm-cm	38%	6.95 microhm-cm

## Rhodium (Engelhard)

25 mil	5.2 microhm-cm	80 mil	5.33 microhm-cm
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\*Base molybdenum supplied by Sylvania with platinum cladding by Engelhard.

The platinum-coated molybdenum was supplied by Engelhard Industries on Sylvania molybdenum. No chemical analysis of the platinum-clad molybdenum is available.

## 2. Tensile-Strength Measurements

During this program, Melpar will develop a 2000°F power wire for aerospace applications. Although this will not be a structural member, it must still have sufficient strength to ensure function operation during installation as well as in the anticipated environment. Accordingly, the target specification for the selected wire is a minimum tensile strength of 35,000 psi at 2000°F.

While the ultimate strength is of primary interest, a knowledge of both the total elongation and elastic modulus will enable a more complete characterization of the material behavior. This information will supplement metallurgical studies of possible diffusion or growth of intermetallic boundaries in the case of clad metals, and define the degree of annealing or cold working in many instances.

It would be desirable to use either strain-gauge techniques, or normal extensometer equipment to record the stress-strain curve for wire directly under tensile load. Unfortunately, strain gauges from 0.025 and 0.080 inch wire are not available, and existing extensometer equipment will not grip these wires without either slippage or failure because of the reduction of the cross section at the point of grip. Even if these could be used, the maximum temperature of 2000°F is out of the question. Consequently, one is left with no alternative but to use a long-gauge length and monitor the crosshead motion of the testing machine to determine elongation as a function of load. To use cross-head motion as an accurate measure of extension under load, it becomes necessary to find a means of gripping the small wires that will hold tightly enough to prevent slippage in the jaw without deforming or weakening it. Serrated jaws tend both to cut into the wire and to reduce the gripping area which leads to neckdown and fracture either in the jaw or at the interface. Smooth jaws tend to flatten the specimen to the point that it eventually loosens, causing slippage. Collets work extremely well for brittle materials but, in the case of wires, they must be tightened until the sample is again deformed if slippage is to be avoided and, again, the sample breaks in the jaw.

Self-tightening wire grips do not maintain a constant gauge length as they tighten, although they do afford a very effective grip on the specimen.

The most efficient grips found during this study were a set of three-jawed Jacobs Chucks, modified to allow cooling at elevated temperatures and adapted to the existing grip mounts on the testing machines. At loads below 200 pounds, the table-model Instron tensile tester is used, while loads above this range require the use of the Tinius-Olsen Universal Tester.

To assure that no slippage occurred when the Jacobs Chucks were used as grips, a measured sample was placed in the grips and the exact distance between the grips (effective gauge length) was measured. The sample was then loaded until elongation was exhibited. After test, the sample was again measured, and the amount of elongation was exactly that recorded by monitoring crosshead movement.

A furnace was constructed with a hot zone uniform to 1% at 2000°F over 5-1/2 inches. Thus, it is possible to use a 6-inch sample with a gauge length known to within 10% for determinations at temperature. This furnace also has provision for use of an inert atmosphere of argon so that unprotected molybdenum can be used as a standard or criteria for examination of clad molybdenum.

To conserve material and labor expense during the initial screening tests, 2-inch samples were tested and only ultimate strength determined. This data is given in table II for ambient and 2000°F.

### 3. Dielectric-Strength Measurements

To supply preliminary data to establish the relative performance of insulating materials with respect to voltage breakdown at elevated temperatures, a brief study was made of the dielectric strength of magnesium oxide. Samples were prepared from MgO powder by dry-press techniques. These were in the form of 2-inch discs ranging in thickness from 0.093 inch to 0.189 inch. The highest dielectric strength at room temperature was approximately 160 volts per mil in the thinnest sample with the thickest sample yielding a value of 105 volts per mil. At 2000°F, the thin sample, 0.074 inch thick, exhibited a dielectric strength of 43 volts per mil.

### 4. Conductor-Insulator Compatibility and Oxidation Resistance

Compatibility tests were run by heating about 1/2 inch to 1-inch lengths of 80-mil wire together with the various insulator materials at 2000°F for 15 hours. The molybdenum wires were heated in a pure argon atmosphere and the rhodium wires in air. A Lindberg model GT-34, atmosphere furnace was used for these tests. The insulating materials tested were:

MgO grain	-	General Electric Co.
Al <sub>2</sub> O <sub>3</sub> grain	-	Norton Co.
Fiberfrax fiber	-	Carborundum Co.
Quartz fiber	-	General Electric Co.

Figures 9-14 show the results of tests on molybdenum wire. As can be seen by comparison of the unheated control wire with the heated, but unexposed to insulation wire, slight oxidation occurred on the surface of the wire. It was also noticed that the wire became slightly

Table II

## AVERAGE ULTIMATE STRENGTH OF WIRE

<u>Metal</u>	<u>Manufacturer</u>	<u>Diameter</u>	<u>Room Temp</u>	<u>2000°F</u>
Rh	Englehard	0.025	151,700 psi*	17,500 psi*
		0.080	Not run	21,200 psi*
Mo No. 1	Fansteel	0.025	122,800 psi	35,600 psi
Mo No. 2	Sylvania	0.025	158,900-190,500 psi	42,800 psi
		0.080	118,400 psi	42,600 psi
38% pt clad Mo	Englehard (Sylvania Mo)	0.025	134,700 psi	54,400 psi
		0.080	97,200 psi*	52,100 psi
25% pt clad Mo	Englehard (Sylvania Mo)	0.025	144,100 psi	57,600 psi
		0.080	88,700 psi*	50,600 psi

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\*Only one sample of each of these was run.

Note: Wide variation of data was evidenced on samples taken from opposite ends of a 150-foot coil of Sylvania Mo.

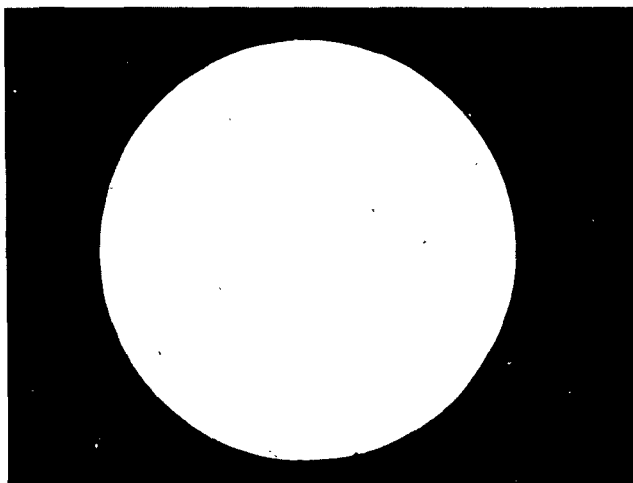


Figure 9. Fansteel Molybdenum Wire, 80-Mil Diameter, 30 X, As Received

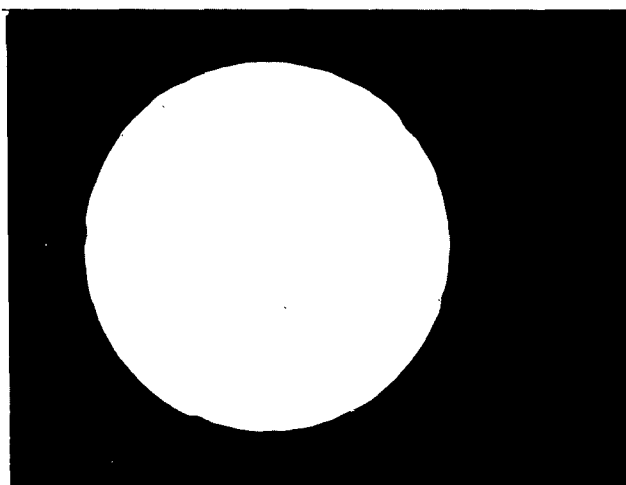


Figure 10. Fansteel Molybdenum Wire, 80-Mil Diameter, 2000°F - 15 Hours in Argon



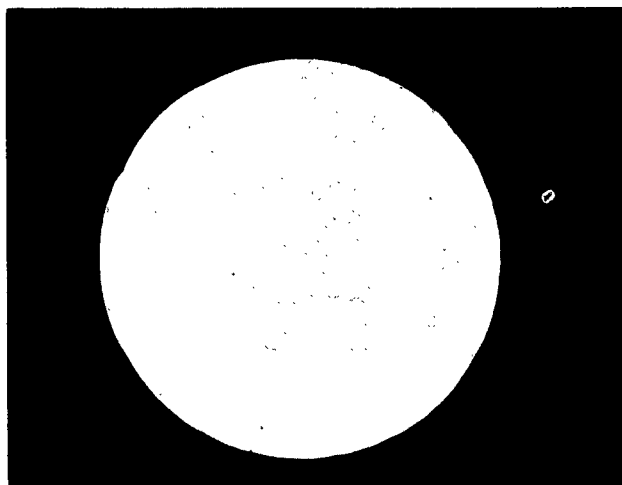


Figure 11. Fansteel Molybdenum Wire, 80-Mil Diameter, 30 X, Heated 2000°F - 15 Hours With MgO Insulation

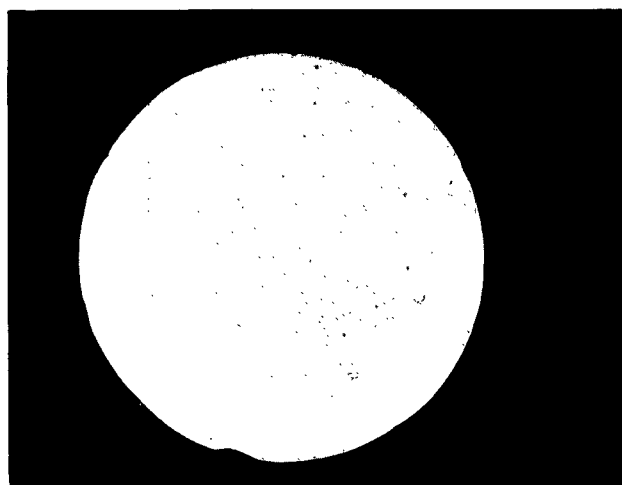


Figure 12. Fansteel Molybdenum Wire, 80-Mil Diameter, 30 X, Heated 2000°F - 15 Hours With  $\text{Al}_2\text{O}_3$  Insulation

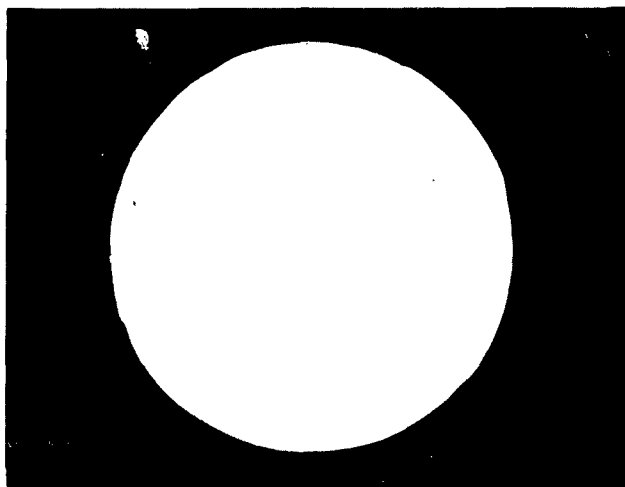


Figure 13. Fansteel Molybdenum Wire, 80-Mil Diameter, 30 X, Heated 2000°F - 15 Hours With Quartz Insulation

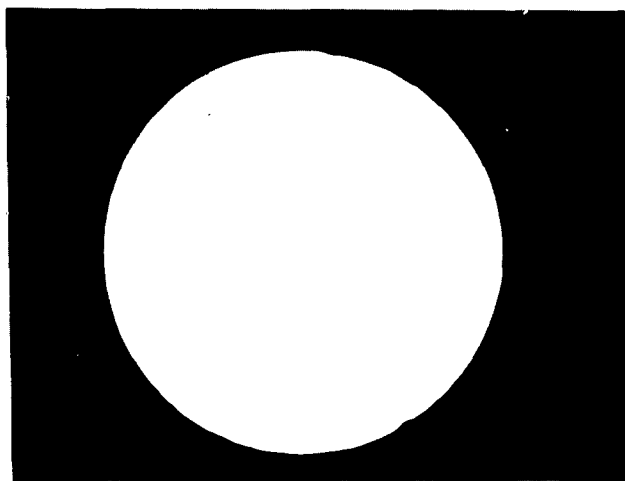


Figure 14. Fansteel Molybdenum Wire, 80-Mil Diameter, 30 X, Heated 2000°F - 15 Hours With Fiberflux Insulation

embrittled. It also appears that the other wires were unaffected by all of the insulations tested. The slight surface irregularities are probably caused only by oxidation.

Figures 15-20 show the results of tests on rhodium wire. As for molybdenum, slight surface irregularities can be seen. In this case, these are also seen in the control wire. It appears that this wire was etched during processing. No effect can be observed on the rhodium wire because of exposure to any of the insulating materials tested at 2000°F for 15 hours. Weight gain or loss tests showed no significant change in the wire because of these tests.

Rhodium wires heated at 2000°F in air for 15 hours showed negligible weight gains. The wire samples were coated with a thin black oxide, presumably  $\text{RhO}_2$ , formed above 1100°F. Rhodium dioxide dissociates at 2000°F.

Platinum-clad molybdenum wire was obtained from Engelhard Industries. The molybdenum used in this system was produced by Sylvania. Three percentages of platinum-14%, 25%, and 38%-in both the 80- and 25-mil wire were tested for potential use as conductors. Figures 21-26 show sections of all of the wires purchased. The average platinum thickness for each wire is as follows:

25-mil, 14%	-	2 mils
25-mil, 25%	-	2 mils
25-mil, 38%	-	2-1/2 mils
80-mil, 14%	-	2 mils
80-mil, 25%	-	4 mils
80-mil, 38%	-	7 mils

It can be seen from the photographs, however, that the cladding in most cases is very nonuniform. In some cases, the platinum is only one mil in thickness. Unless this process can be improved to provide more uniform coatings, it is doubtful that this type of wire could be used unprotected at 2000°F.

Ten-inch lengths of each of the platinum-clad wires were carefully weighed, then the center 2 inches of each were heated in a narrow furnace at 2000°F for 15 hours. After this test, the wires were observed for oxidation of the molybdenum and weighed to determine weight gain or loss. All of the wires, except the 80-mil 25% and 38% platinum, were severely

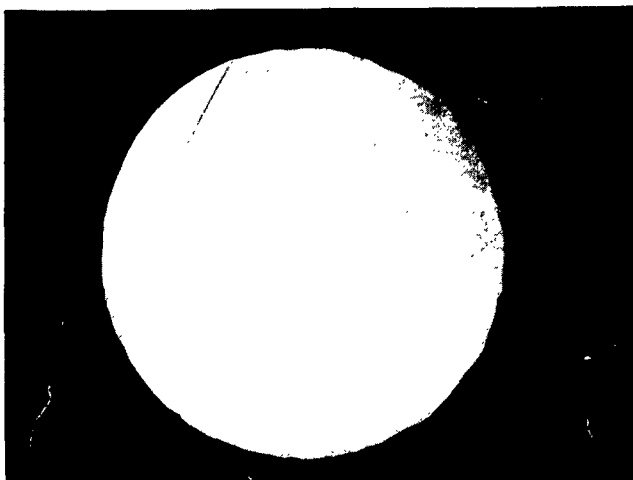


Figure 15. Engelhard Rhodium Wire, 80-Mil Diameter, 30 X, As Received



Figure 16. Engelhard Rhodium Wire, 80-Mil Diameter, 30 X, 2000°F - 15 Hours

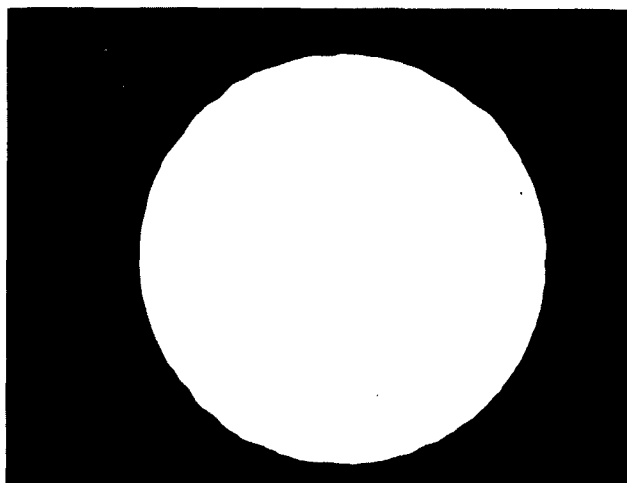


Figure 17. Engelhard Rhodium Wire, 80-Mil Diameter, 30 X, Heated 2000°F - 15 Hours With MgO Insulation

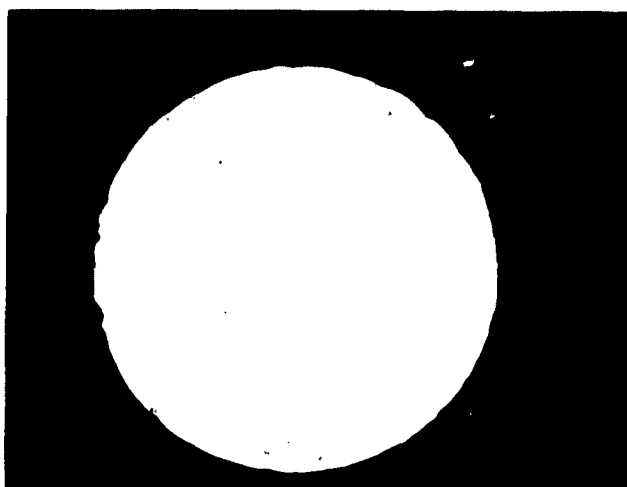


Figure 18. Engelhard Rhodium Wire, 80-Mil Diameter, 30 X, Heated 2000°F - 15 Hours With  $\text{Al}_2\text{O}_3$  Insulation

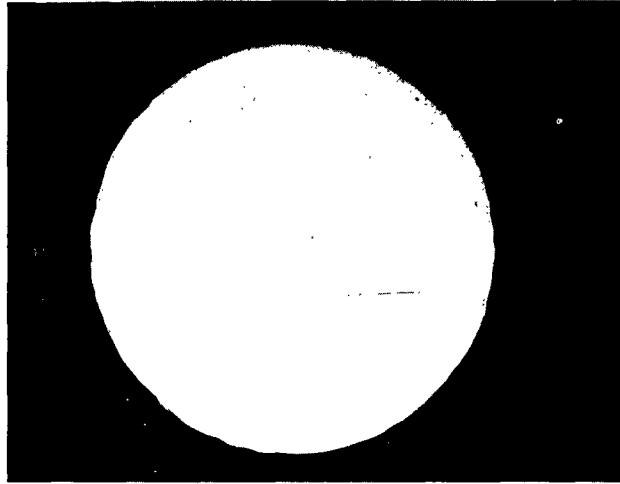


Figure 19. Engelhard Rhodium Wire, 80-Mil Diameter, 30 X, Heated 2000°F - 15 Hours With Quartz Insulation

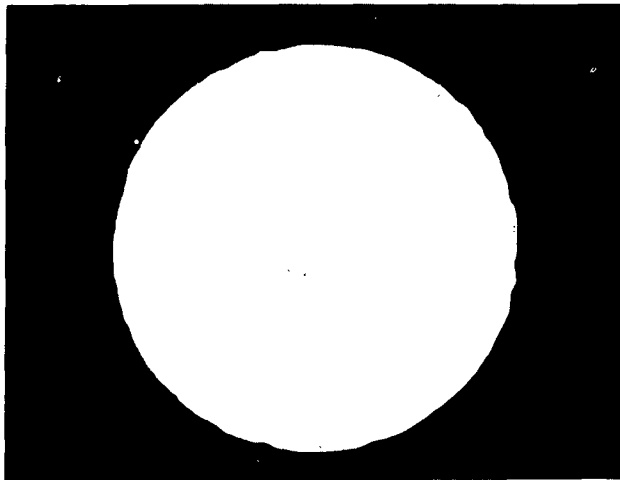


Figure 20. Engelhard Rhodium Wire, 80-Mil Diameter, 30 X, Heated 2000°F - 15 Hours With Fiberflux Insulation



Figure 21. Engelhard Platinum-Clad Molybdenum Wire, 25-Mil, 14% Platinum, 100 X



Figure 22. Engelhard Platinum-Clad Molybdenum Wire, 25-Mil, 25% Platinum, 100 X

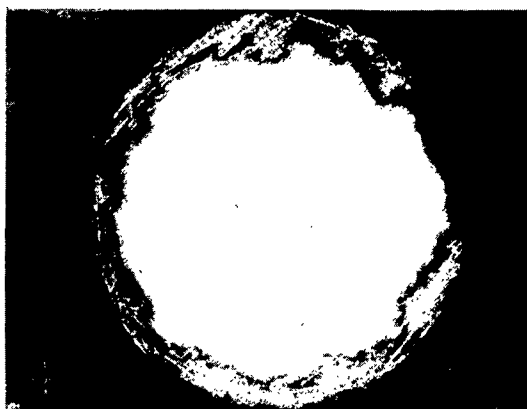


Figure 23. Engelhard Platinum-Clad Molybdenum Wire, 25-Mil, 38% Platinum, 100 X

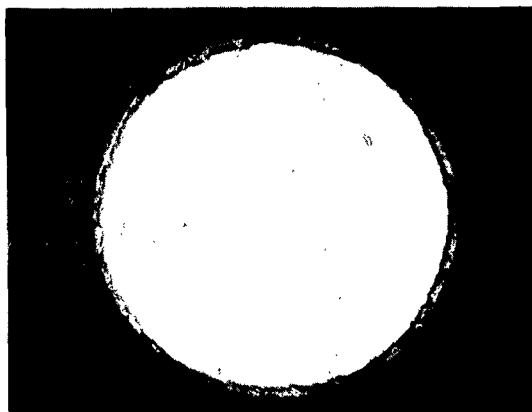


Figure 24. Engelhard Platinum-Clad Molybdenum Wire, 80-Mil, 14% Platinum, 30 X

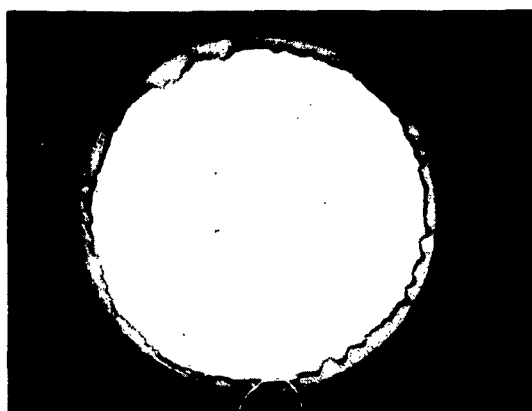


Figure 25. Engelhard Platinum-Clad Molybdenum Wire, 80-Mil, 25% Platinum, 30 X

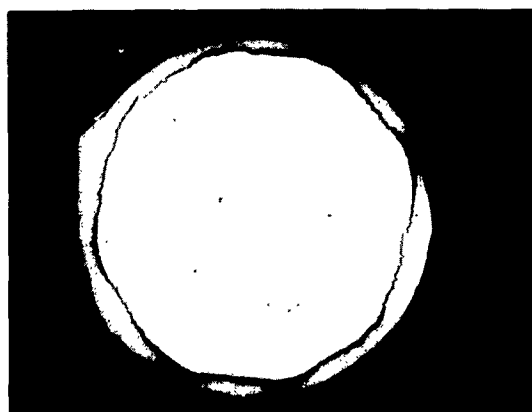


Figure 26. Engelhard Platinum-Clad Molybdenum Wire, 80-Mil, 38% Platinum, 30 X



oxidized, leaving only a platinum shell. The 80-mil wires with 25% and 38% platinum were unaffected by this test. No significant weight gain or loss was detected for either of these two wires. Figures 27-29 show the effects of this heating test on the 25% platinum-clad wires. Figure 27 is a section before heating and figure 28 is a section taken after heating at 2000°F for 15 hours. In comparing these two structures, one can easily see that the molybdenum, in unheated or as-received wire, is in the unannealed or work-hardened condition. A very slight hint of an interface zone (faint gray) indicates a heating or annealing treatment during drawing. After heating (figure 28), a definite reaction zone can be seen. Also, the molybdenum is clearly in the annealed condition. There is no apparent, significant grain-boundary penetration of platinum into the molybdenum. Figure 29, a lower-magnification photograph, does show, however, a more rapid diffusion of platinum into the reaction zone than for molybdenum. This is shown by the numerous voids at the platinum-reaction zone interface, which are absent at the molybdenum interface. This figure is an excellent example of the Kirkendall effect. The platinum-molybdenum phase diagram shown in figure 30 indicates four phases at 2000°F for this system. These four phases are shown in figure 28 as (1) platinum, (2) gray reaction zone, (3) narrow, light-gray zone, and (4) molybdenum. It is believed that this system should be examined further to determine the effects of the inter-metallic phases upon electrical and mechanical properties of this wire system.

#### 5. Design of End Seals and Terminals

Several potential techniques of producing end seals and terminations for a Lewis type III wire were studied. From this study, it appeared that two general types might be the most feasible. These are shown in figure 31. Both make use of a metallized, high-alumina ceramic to which metal parts can be brazed. Type 1 would be for use with a nonoxidizing conductor such as rhodium and Type 2 should be satisfactory for use with wires such as molybdenum or platinum-clad molybdenum. It can be seen from the sketch that the use of a specially constructed termination made from platinum or a similar metal could be brazed over the exposed conductor to protect it from oxidation. Contact of the wire with the termination in this case can be made by spot welding. The termination for type 1 can be made by torch fusion or spot welding.

General fabrication techniques for either type of construction would consist of (1) evacuation of air in the sheath, followed by back filling with argon or another inert gas; (2) swaging the sheath over a crushable MgO insulation, and (3) induction brazing of the metallized alumina end seal onto the sheath and conductor. Probably the most promising sheath material is platinum, although tubing of Inconel 702 or Hastaloy should be satisfactory at 2000°F. Both materials are reported to have negligible oxidation for extended time periods at this temperature. Any of these materials should be suitable for brazing to metallized alumina. The most promising insulation material for this type of wire

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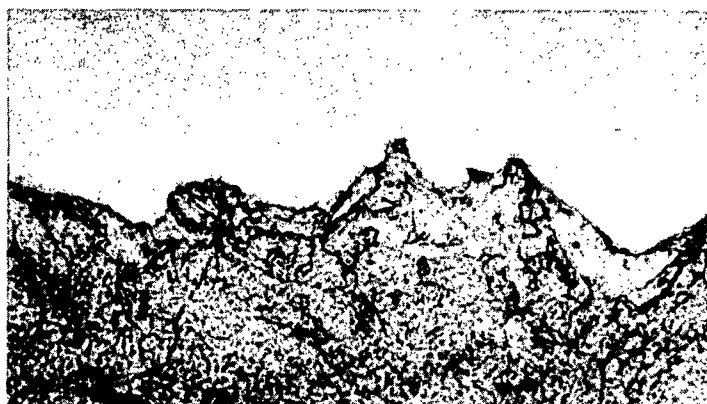


Figure 27. Platinum-Clad Molybdenum Wire, 25% Platinum, 500 X Etched

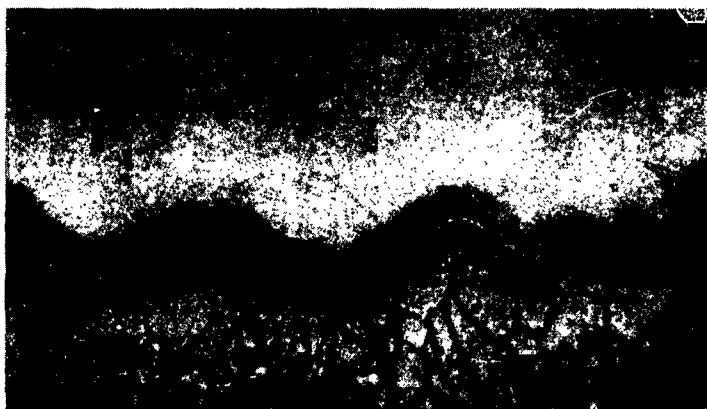


Figure 28. Platinum-Clad Molybdenum, 25% Platinum Heated 2000°F - 15 Hours, 500 X Etched



Figure 27. Platinum-Clad Molybdenum Wire, 25% Platinum, 500 X Etched

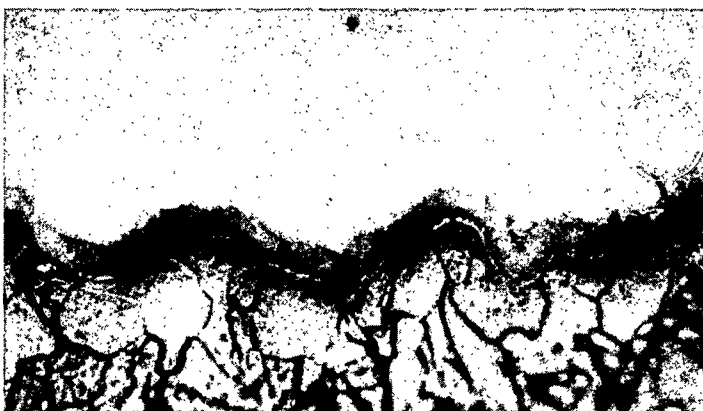
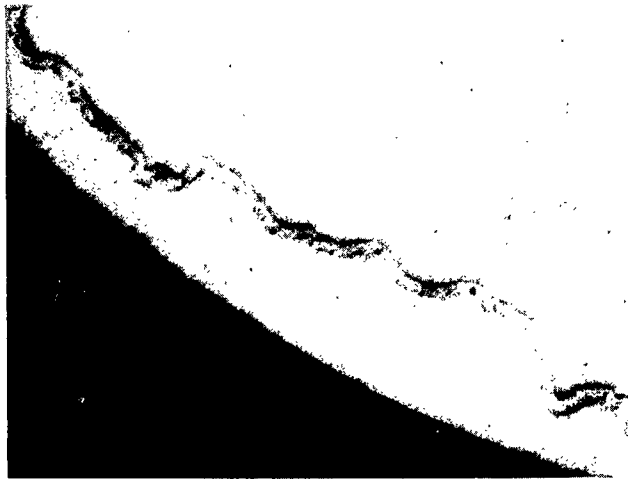
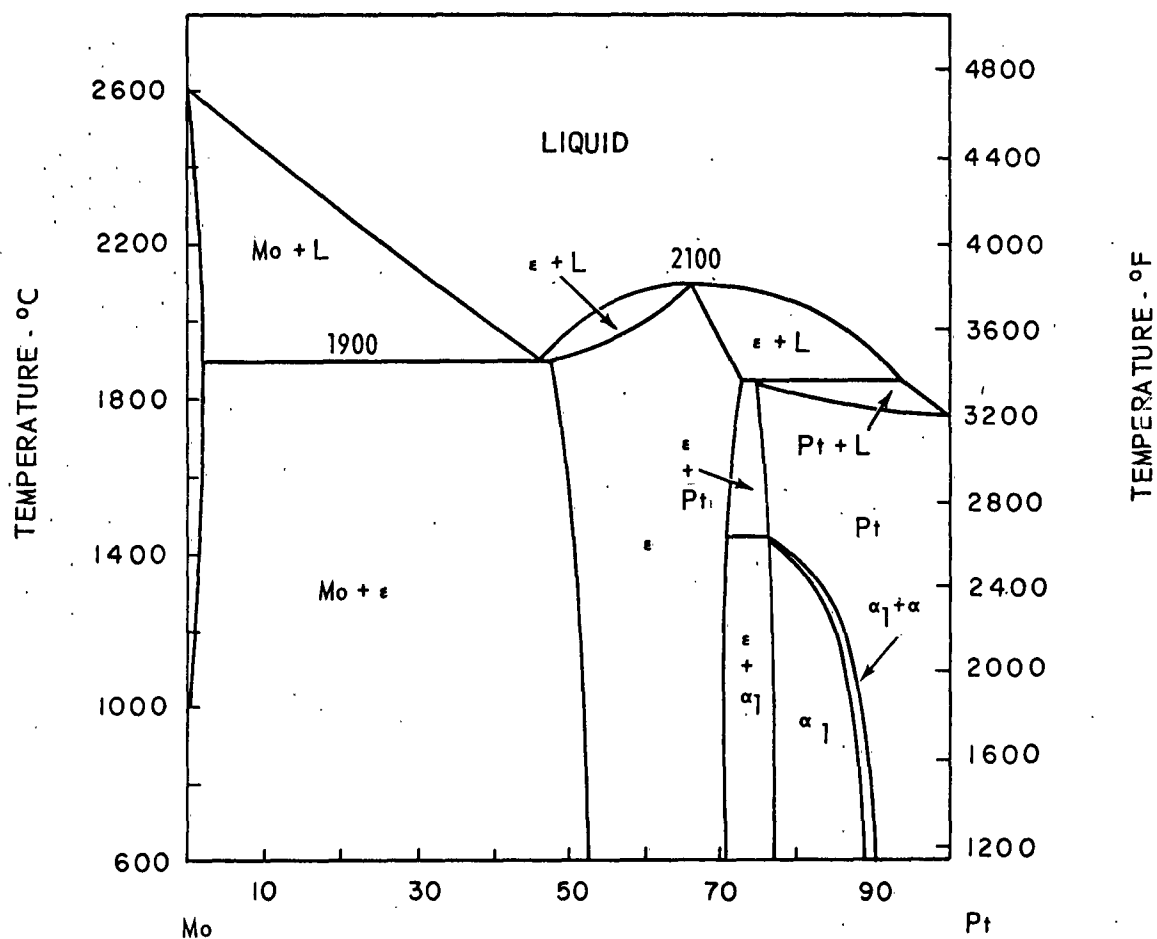


Figure 28. Platinum-Clad Molybdenum, 25% Platinum Heated 2000°F - 15 Hours, 500 X Etched

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**Figure 29. Platinum-Clad Molybdenum, 25% Platinum Heated 2000°F - 15 Hours,  
220 X**



\* TAKEN FROM DMIC 152, APRIL 1961

Figure 30. Platinum-Molybdenum System

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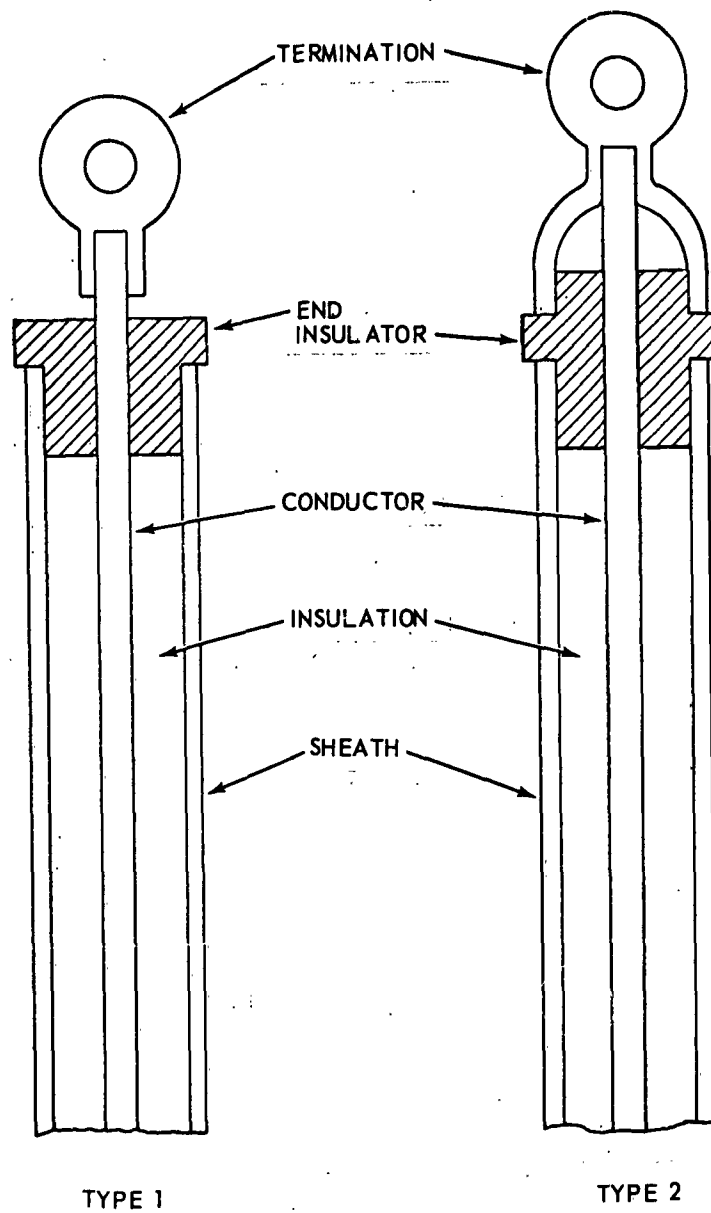


Figure 31. End Seal and Terminator Designs

system is MgO. This is one of the best insulating materials known. The chief difficulty of this type of insulation will be its rather poor flexibility. A palladium-gold braze composition will be used to braze all members of the end seal. This braze melts at about 2300°-2400°F and is oxidation resistant. It should form no low-melting alloys with the other metal members of the termination. The use of induction heating will provide for rapid and localized heating, which is most desirable for brazing in this type of application.

It is planned for at least the early stages of the program to purchase the necessary metallized ceramics. There are several techniques that are used by various vendors to avoid the various problems encountered in this type of work. Consultations will be made with selected vendors to obtain the latest information and the ultimate in materials and design for this type of application.

### III. SUMMARY AND CONCLUSIONS

The two materials considered in this phase of the program have been rhodium and platinum-coated molybdenum. From the oxidation studies, it has been concluded that only rhodium is suitable in the 22-gauge wire, based on oxidation studies. The 22-gauge rhodium had negligible weight gains after 15 hours in air at 2000°F, whereas the 22-gauge, platinum-coated molybdenum was completely burned out.

The 12-gauge, platinum-coated molybdenum had a negligible weight loss after 15 hours in air at 2000°F. Brittle reaction zones were noted at the Pt-Mo interface, as shown in figure 29. The 12-gauge rhodium showed no oxidation under similar conditions.

In all instances, the resistivity of the pure rhodium was lower than the resistivity of the platinum-coated molybdenum.

For these reasons, rhodium has been selected as the conductor material for the next phase of the program. Some of the important physical properties of rhodium are given in table III.

No reaction was noted between rhodium and MgO when heated at 2000°F for 15 hours. Because of the low density of MgO and high dielectric strength, it will be used as the insulating material for the fabrication of power wire.

It is reported that cast, high-purity rhodium is not workable cold, but can be readily forged above 800°C. The hot-worked metal is coarse grained and is not ductile at room temperature but, by continuing to work the metal at gradually decreasing temperatures, a fibrous structure is developed and the metal becomes moderately workable at room temperature. Wrought rhodium may be adequately softened by annealing at 800°C and, in this condition, may be cold worked by about 40%.

Difficulty was encountered in bending the 12-gauge rhodium wire at room temperature into the U sample required for resistivity measurements. The sample had to be heated to red heat and then bent. It is hoped that zone-refined rhodium will completely eliminate this problem of flexibility of the wire.



Table III

## PROPERTIES OF RHODIUM

Rhodium	Rh
Atomic number	45
Atomic weight	102.91
Density 20°C, g/cc	12.44
Density 20°C, lb/in <sup>3</sup>	0.447
Atomic volume cc/gm atom	8.27
Melting point, °C	1966 + 3
Melting point, °F	3571 ± 5
Boiling point, °C	4500
Boiling point, °F	8130
Specific heat, 0°C cal/gm/°C	0.059
Coef. of linear expansion, Micro-in/in/°C	8.3
Coef. of linear expansion, Micro-in/in/°F	4.6
Modulus of elasticity, psi	42.5 x 10 <sup>6</sup>
Lattice constant, Å	3.804
Closest approach of atom A	2.689
Thermal conductivity, 17°C, cal/cm <sup>2</sup> /cm/sec/°C	0.21
Magnetic susceptibility, 18°C, egs	1.14 x 10 <sup>-6</sup>
Emissivity at x = 0.65 μ solid	0.24
Emissivity at X = 0.65 μ liquid	0.30
Resistivity, μohm-cm, 20°C	4.5
Temperature coef. of resistivity between 0°C and 100°C	0.00463

#### IV. FUTURE WORK

Rhodium wire will be used for the conductor material during the next phase of the program because of its superior oxidation behavior in all sizes and its low resistivity. Rhodium of 99.95% purity supplied by Engelhard Industries, Inc., and float zone refined rhodium will be tested. The increased purity over the present 99.8% purity should further lower the resistivity and greatly increase the flexibility and ductility of the rhodium wire.

The first complete wire systems will be made with rhodium wire, MgO insulation, platinum sheathing and terminals, and metalized alumina in end seals.